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INTERNATIONAL APPLICATION NO.
PCT/IL99/00227INTERNATIONAL FILING DATE
2 May 1999PRIORITY DATE CLAIMED
1 May 1998TITLE OF INVENTION METHOD AND APPARATUS FOR CAPACITY INCREASE AND ENHANCED COMMUNICATIONS
PERFORMANCE IN CATV NETWORKS


APPLICANT(S) FOR DO/EO/US SEGAL, Mordechai; SHALVI, Ofir; and REZNIC, Zvi

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 29(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☐ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A **FIRST** preliminary amendment.
☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: 1) Postcard

U.S. APPLICATION NO. 09/674665		INTERNATIONAL APPLICATION NO. PCT/IL99/00227		ATTORNEY'S DOCKET NUMBER P-2450-US																					
17. <input checked="" type="checkbox"/> The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO\$1000.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO\$860.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO\$710.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4)\$690.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4).....\$100.00 ENTER APPROPRIATE BASIC FEE AMOUNT =				CALCULATIONS PTO USE ONLY																					
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Note: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.																									
<div style="display: flex; justify-content: space-between;"><div style="width: 45%;">SEND ALL CORRESPONDENCE TO: Jerome R. Smith, Jr. EITAN, PEARL, LATZER & COHEN-ZEDEK One Crystal Park, Suite 210 2011 Crystal Drive Arlington, VA 22202-3709 Tel: (703) 486-0600 Fax: (703) 487-0800</div><div style="width: 45%; text-align: center;"> SIGNATURE: Jerome R. Smith Jr. NAME 35,684 REGISTRATION NUMBER</div></div>																									

Method and Apparatus for Capacity Increase and Enhanced
Communications Performance in CATV Networks

Related Applications

5 This application claims the benefit of U.S. Provisional Applications Serial
Numbers 60/083,934 and 60/083,952, both of which were filed on May 1, 1998 under
35 U.S.C. § 119(c).

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Technical Field

20 The present invention relates generally to communication methods and systems
and in particular to communication methods and systems implemented using CATV
(Cable Television) systems.

Background of the Invention

25 Cable television (CATV) systems were originally intended to deliver analog
television signals to homes in an essentially unidirectional manner. However, the
coaxial cable used to carry these signals can support bidirectional transmission of
signals, i.e., transmission both to and from the home. As a result, cable television
companies have begun to provide data communications services to meet consumers'

growing demand for high speed data transmission over computer networks, such as the Internet.

Devices known as cable modems have been developed to convert digital data to a modulated radio frequency (RF) signal, and vice versa, for transmission on a CATV system. This conversion is performed both by a cable modem at the subscriber's home and, on the other end, by headend equipment handling multiple subscribers. Thus, the subscriber receives data from a computer network using a downstream channel and transmits data to the network using an upstream channel.

As computer networks deliver increasing amounts of content to users, a need has arisen for increased throughput and communications robustness. It is also essential that communications equipment operate over a wide range of channel impairments, which can include, for example, ingress noise, burst noise, impulse noise, linear distortions, non-linear distortions, and adjacent channel interference. Moreover, the different types of services that use CATV systems give rise to additional needs. For example, for data services, such as Internet access, a high packet throughput and a low packet error rate are primary considerations. For such applications, low delay is not a key consideration. For multimedia services, such as speech, video, and telephony, however, low delay is the primary consideration. It is desirable to minimize the periods of a high bit error rate (BER) for these applications. Additionally, compatibility with existing standards and equipment is important for all applications.

Summary of the Invention

According to one embodiment of the present invention, a transmission arrangement is used for transmitting a data signal using a cable television transmission medium. An encoder encodes an input data stream as an encoder output signal. Adjacent channel interference in this signal is then reduced using a transmission filter arrangement, thereby generating a filter output signal. A modulator modulates the filter output signal to generate a modulated radio frequency signal for transmission using the cable television transmission medium. Another embodiment is directed to a

communication system that, in addition to the above, includes a receiver arrangement that generates a stream of detected data based on the received modulated radio frequency signal.

Yet another embodiment of the present invention is directed to an analog front end arrangement for use in the communication system. The analog front end arrangement comprises a plurality of band pass filters coupled to receive a modulated radio frequency signal. Each of the band pass filters is centered around a different frequency. The sample rate is less than the Nyquist rate so as to cause aliasing deliberately. A multiplexer receives output signals from the band pass filters and couples a selected one of the band pass filter output signals to an output of the multiplexer. An analog to digital converter provides a digital signal, generated as a function of the output of the multiplexer and a clock signal, to a digital receiver. Sample rate logic provides, as a function of the center frequency, a select signal to the multiplexer, a rate parameter to the clock signal generator, and a spectrum inversion indication to the digital receiver.

Other embodiments are directed to methods for transmitting or communicating a data signal using a cable television transmission medium.

Another aspect of the present invention provides methods and arrangements for robust communications over noisy communications channels using data retransmission and/or diversity techniques. In one particular embodiment, a communication arrangement includes an encoder that reproduces a symbol or FEC block represented by a segment of an input data stream a predetermined number of times. A transmission arrangement having a plurality of transmission channels transmits each reproduced symbol or FEC block using a distinct transmission channel. A receiver performs soft-combining of signals received from the outputs of the transmission arrangement.

The present invention can be implemented in full compliance with current network specifications and/or on top of the existing specifications in a manner that enables co-existence of advanced modems designed according to the present invention with current modems.

Brief Description of the Drawings

In the drawings, in which like reference numbers represent like components throughout the several views,

5 Figure 1 depicts a CATV digital communications system operative according to the Data Over Cable Service Interface Specification (DOCSIS) protocol;

Figure 2 depicts a frequency grid over an upstream channel of a CATV network operative according to the MCNS specification;

10 Figure 3 depicts a reduced channel spacing frequency grid of the upstream channel that can be used in conjunction with the MCNS specification according to an embodiment of the present invention;

Figure 4 depicts a simplified block diagram of a communications apparatus constructed and operative for upstream CATV applications according to an embodiment of present invention;

15 Figure 5 depicts an example of an adaptive equalizer that can be used in conjunction with the embodiment depicted in Figure 4;

Figure 6 depicts an example decoder structure that can be used in conjunction with the embodiment depicted in Figure 4;

Figure 7 depicts an example structure of a modified Reed-Solomon decoder that can be used in conjunction with the embodiment depicted in Figure 4;

20 Figure 8 depicts a structure of an analog front end that can be used in conjunction with the embodiment depicted in Figure 4;

Figure 9 depicts a structure of a modified slicer that can be used in conjunction with the embodiment depicted in Figure 4;

25 Figure 10 depicts a general scheme employing diversity or retransmission techniques, or both, over different MCNS channels;

Figure 11 depicts a signal retransmission technique that can be used in conjunction with the embodiment depicted in Figure 10;

Figures 12A-12B depict two example symbol mapping schemes that can be used in conjunction with the retransmission technique depicted in Figure 11;

Figure 13 depicts an example signal diversity technique that can be used in conjunction with the embodiment depicted in Figure 10; and

Figure 14 depicts a symbol mapping scheme that can be used in conjunction with the signal diversity technique depicted in Figure 13.

5 The invention is amenable to various modifications and alternative forms. Specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and
10 scope of the invention as defined by the appended claims.

Detailed Description

15 The present invention is applicable to a variety of communications networks operating over a cable television (CATV) infrastructure. An appreciation of various aspects of the invention can be gained through a discussion of various application examples operating in such an environment.

20 According to one example embodiment of the present invention, channel throughput and communications robustness are increased in the upstream or return channel of a CATV network. A filter arrangement is used to reduce interference between adjacent frequency channels, facilitating the use of a frequency grid characterized by reduced channel spacing.

25 Referring now to the drawings, Figure 1 depicts a CATV digital communication system embodying the present invention and operating according to the MCNS specification. For additional information regarding this specification, reference is made to Data-Over-Cable Interface Specifications: Radio Frequency Interface Specification SP-RF1101-970321, published by MCNS Holdings, L.P. on March 21, 1997 (hereinafter referred to as the MCNS specification). The system includes one or more cable modems (CMs) 101a, 101b and a CATV transmission medium 102. It should be noted that, while Figure 1 depicts two CMs, a greater or lesser number of CMs can be

present in the system. A cable modem terminating system (CMTS) 103, which is part of CATV head-end equipment 104, is present at the other side of the network.

Information is transmitted from the CMTS 103 to the CMs 101 using a downstream channel 105, and from the CMs 101 to the CMTS 103 using an upstream channel 106.

5 The CMs 101a, 101b include upstream transmitters 107a, 107b that receive input data 108a, 108b and transmit the input data 108a, 108b using a Quadrature Phase Shift Keying/Quadrature Amplitude Modulation (QPSK/16QAM) modulation scheme with a configurable transmission pulse, pre-equalizer parameters, power level, carrier frequency, symbol clock, and Reed-Solomon forward error correction (FEC) code
10 parameters. Transmission is performed in a burst mode frequency/time division multiplexing access (FDMA/TDMA) scheme in which each CM 101 transmits requests for bandwidth allocation, and in which a channel allocator 109 sends control messages to the CMs 101 via the downstream channel 105, indicating the time period in which the addressed CM 101 can transmit. The CM 101 is capable of modifying its signal
15 parameters, including transmission power, carrier frequency, transmission pulse, and pre-equalizer parameters, according to these control messages from the channel allocator 109.

The CMTS 103 includes a receiver 110 and the channel allocator 109. The receiver 110 detects the information bits fed into the inputs 108a, 108b of the upstream
20 transmitters 107a, 107b. The receiver 110 then estimates the parameters of the received signals, and outputs these parameters to the channel allocator 109. The channel allocator 109 then allocates frequency ranges and configures transmission parameters for the individual CMs 101 in a manner that will make efficient use of the channel bandwidth and that will enable the receiver to detect the signals properly.

25 Figure 2 depicts a frequency constellation of a CATV network operative according to the MCNS specification. Signals 201a-201c have the same nominal symbol rate, while signal 201d has a larger symbol rate, and signal 201e has a lower symbol rate. The nominal bandwidth of each signal 201a-201e is 1.25 times its respective symbol rate.

Figure 3 depicts an example of a reduced channel spacing frequency grid with which the present invention can be used. The channel spacing is less than the signal bandwidth, which is 1.25 times the symbol rate of the signals. Such a system uses overlapped transmission scheme, such as that disclosed in U.S. Patent 5,710,797, issued on January 20, 1998, assigned to the instant assignee, and entitled METHOD AND APPARATUS FOR DIGITAL COMMUNICATION IN THE PRESENCE OF CLOSELY SPACED ADJACENT CHANNELS, the disclosure of which is hereby incorporated by reference in its entirety.

Referring now to Figure 4, a simplified block diagram is depicted of a communications apparatus constructed and operative for upstream CATV applications according to a particular embodiment of the present invention. The apparatus of Figure 4 includes a transmitter 401 that transmits a digital communication signal 402 through an upstream channel 403. The transmitter 401 comprises an encoder 404, a transmission filter 405, and a modulator 406. The transmission filter 405 comprises a cascade of a spectral shaping filter 407, a square-root raised cosine filter 408, a fixed shaping filter 409, and a trained pre-equalizer 410. This transmission structure may be supported by the current MCNS specification, and therefore may be supported by current MCNS implementations.

The encoder 404 can include any Forward Error Correction (FEC) code, such as Reed-Solomon encoding. The encoder 404 optionally uses an interleaver within the packet in order to counteract impulse/burst noise. Using an interleaver in this manner, however, involves modifications that may not be consistent with existing DOCSIS specifications. Alternate signal constellations can be used instead of those specified in the MCNS specification. Examples of such alternate signal constellations include, but are not limited to, $\pi/4$ -QPSK, offset-QPSK, 8PSK, 32QAM, 64QAM, 128QAM, and 256QAM. The choice of a particular signal constellation is dependent on channel conditions. Tomlinson precoding can also be used to avoid a DFE at the receiver 411, but this technique also involves modifications that may not be consistent with existing DOCSIS specifications.

According to a particular implementation, the spectral shaping filter 407 comprises a duo-path filter $(1+\alpha z^{-N})$, where α can be a complex number) or any other pre-equalizer that can be used to achieve an approximation to the water-pouring spectral density in conjunction with a DFE receiver, e.g. $(1+e^{j\omega_0} z^{-1})$ for elimination of narrow-band interference at ω_0 . The purpose of the shaping filters 407, 408, and 409 is to reduce adjacent channel interference (ACI) to facilitate the use of a frequency grid characterized by reduced channel spacing.

The fixed shaping filter 409 is designed for a more or less known level of signal-to-noise (SNR) ratio and Signal-to-Interference (C/I) ratio, and may be loaded during ranging when the C/I and SNR are assessed. The trained pre-equalizer 410 performs essentially the inverse $1/H$ of the transfer function H of the upstream channel 403 and is trained at the receiver 411, where the parameters describing the upstream channel 403 are transmitted to the CM 101 through a downstream channel 105 of Figure 1.

The transmitted signal 402 is impaired by the linear distortion H of the upstream channel 403, by non-linear distortions, and by additive noise sources, including ingress noise and adjacent channel interference. The effects of ingress noise and adjacent channel interference are conceptually illustrated in Figure 4 as summing blocks 412 and 413, respectively.

The receiver 411 includes an analog front end 420, a demodulator 421, and a modified matched filter (MMF) 414, which performs a convolution of a square-root raised cosine filter 415 and a pre-calculated filter 416 working at N times the symbol rate (e.g., $N=2$). The MMF filter 414 can be loaded from a table according to the estimated C/I and SNR. It should be noted that the pre-calculated filter 416 can be jointly designed with the transmission filter 405 to improve the overall SNR and C/I at the receiver 411. The output of the MMF 414 is provided to an adaptive equalizer 417, followed by a decoder 418, which may include additional filtering, a Viterbi detector, and a FEC decoder.

The MMF 414 can be designed to have low side lobes in the time domain. This is a deviation from an ideal square-root raised-cosine pulse. This deviation might be compensated for by the pre-equalizer 410. The reduction in side lobes in the time domain can also prevent the propagation of an impulse noise to symbols that were not originally hit by the impulse.

Figure 8 depicts an example implementation of an analog front end 420. This implementation includes a filter bank 801 of band pass filters (BPFs) 801a, 801b, ..., 801n. Each BPF 801 is centered around a different frequency. The output of the BPFs 801, denoted in Figure 8 with reference numerals 804a, 804b, ..., 804n, is input into an analog multiplexer 802. Sample rate logic 815 generates a select signal 803 as a function of the center frequency. The select signal 803 selects which of the BPF outputs 804 is coupled to an output 805 of the multiplexer 802.

A parameter F_s , also generated by the sample rate logic 815 as a function of the center frequency and denoted with reference numeral 806, defines the sample rate of an analog to digital converter (ADC) 809 and is provided by a clock generator 810. In this embodiment, the sample rate can be smaller than the Nyquist rate and can be chosen such that deliberate aliasing will shift the center frequency of the desired signal from its original frequency F_{cs} , which can be greater than $F_s/2$, to a new frequency F_{cb} , such that F_{cb} is less than $F_s/2$. Thus, deliberate aliasing facilitates the use of discrete ADC components to sample signals having a frequency greater than half the frequency of the ADC. It will be appreciated by those skilled in the art that, when aliasing occurs due to undersampling, the digital receiver 808 should compensate for it. Accordingly, the sample rate logic 815 also provides a spectrum inversion indication 820 to the digital receiver 808 to indicate that undersampling has occurred.

An example of an adaptive equalizer is depicted in Figure 5. The adaptive equalizer of Figure 5 is an adaptive Decision Feedback Equalizer (DFE) operating in a noise prediction configuration 501, and it may be preceded by an adaptive FSE 502. By using the adaptive FSE 502, the magnitude of the DFE taps can be reduced using tap leakage procedures, thus reducing DFE error propagation. To avoid any error

propagation at all, the adaptive FSE only can be used, completely avoiding the DFE. The equalizer taps are modified by a Linear Mean Square (LMS) approach. It can be trained during the ranging phase of the CMTS and/or pre-loaded using prior knowledge of channel spacing, and perhaps C/I and SNR.

5 Figure 6 depicts the structure of the decoder when a duo-path pulse $1+\alpha z^{-N}$, where α can be a complex number, is used. An equalizer 601 is adjusted to achieve a sum of two symbols at its output. The output of the equalizer passes through a $1+\alpha z^{-N}$ filter 602, and then goes to a Viterbi detector 603. For example, if the encoder output 419 in Figure 4 is QPSK symbols $\pm I \pm jQ$, then the modified slicer 604 of the DFE searches for constellation points $I+jQ$, where I and Q can have values of 2, 0, and -2. The
10 adaptive DFE 605 is trained to minimize the error between the slicer input and the slicer output.

 The complexity of the Viterbi is 4 states and 16 branches per QPSK symbol and 16 states and 256 branches in 16QAM. As an alternative, a reduced 16QAM version of
15 4 states and 16 branches per symbol can be used.

 It should be noted that, instead of a DFE, advance equalization techniques such as a maximum likelihood sequence estimator (MLSE) can be used. The idea here is to implement noise prediction and compensation of deliberate ISI due to transmission pulse using a reduced Viterbi equalizer.

20 The FEC decoder 606 can be implemented using a conventional Reed-Solomon decoder, assuming this is the code being used in the system. Alternatively, one can use the configuration depicted in Figure 7, where the burst noise identifier 701 identifies an exceptional data point based on inputs from an Analog Front End (AFE) 702 and a QPSK/16QAM receiver 703 and analyzes the presence and the length of noise burst.
25 The Reed-Solomon decoder 704 uses erasures for the data bytes that are suspected to be affected by noise.

 The exceptional data points are detected by either saturations or very large values of the data at the signal path (e.g., at the slicer input), a sequence of large error values at the slicer, or yielding of different symbol decisions for the two signals in

retransmission mode. The receiver has a state machine that estimates burst duration according to the indication of exceptional data points and puts the Reed-Solomon decoder in an erasure mode during the burst. In addition, the receiver performs clipping of signals with exceptionally large magnitudes.

5 The present invention can be used in conjunction with reduced spaced signal constellations, such as that depicted in Figure 3, by following the procedures described in U.S. Patent 5,710,797. In particular, the algorithm may iterate as follows. For a set of overlapping signals, the previously processed signal is subtracted from the received signal. A signal is then detected using the receiver 410 and is remodulated. The
10 algorithm should start with the signal having the best C/I and SNR, which is typically the strongest signal, or a signal that has only one overlapping ACI, rather than two.

Pairs of severely interfering signals may be jointly detected using an encoded joint maximum likelihood approach, as part of the iterations of a method, the general procedure of which is outlined in U.S. Patent 5,710,797. The joint maximum likelihood
15 procedure involves a Viterbi-like algorithm for which a trellis diagram with a branch metric is defined. The complexity of such an approach, based on a memory constraint of three symbols for each signal, is 16 states and 256 branches per symbol with QSPK and 256 states and 64K branches per symbol in 16QAM. The number of transitions can be significantly reduced using a reduced state Viterbi algorithm, e.g., by discarding
20 states in the trellis diagram that are unlikely for the current signal sample. The algorithm then selects a survivor path for each of the remaining new states based on the cumulative metric for all possible paths entering the new state from the previous states, followed by the selection of the leading path, and detection of the information bits. The algorithm then discards unlikely new states based on the cumulative metrics.

25 The present invention can also be used in conjunction with a frequency hopping scheme, using joint frequency/time axis forward error correction and interleaving.

As part of the signal acquisition stage, in which the received signal parameters are estimated, the receiver 411 makes use of a preamble field in a data packet. In the presence of impulse and burst noise, the preamble should be longer than the duration of

the longest error burst that can be recovered by the receiver (i.e., at least $2t$ bytes if Reed-Solomon block code $(N-t, N)$ is used, where N is the block size. The preamble is split into sections, and the receiver identifies sections that are noisy, for example, according to the residual error between the incoming signal and the expected signal according to the known training data and estimated parameters. Sections that are noisy due to impulse or burst noise are neglected.

In case the receiver is capable of recovering a very long error burst, in particular, if interleaving is used, then the packet structure PDDDPDDDD...D may be used, where P is a preamble section and D is a data section. The distance between P sections will be larger than the maximum burst length that can be received.

Acquisition performance can be severely affected by narrow-band interference, such as ingress noise, e.g., narrowband interference, or partially overlapping channels. Thus, it is particularly advantageous to use a preamble that has low spectral density at frequency regions of high noise and high spectral density at frequency regions of low noise. This can be achieved using a pre-equalizer in the transmitter, or by using a non-white sequence of symbols. As a result, the interference of the transmitted preamble into overlapping adjacent channels will be reduced, enabling robust acquisition of overlapping signals.

Figure 9 depicts a modified slicer structure that can be used in connection with the communication apparatus of Figure 4. In this modified slicer structure, a slicer 901 produces an estimate 902 of the original transmitted symbol 419 of Figure 4. This estimate is filtered by a digital filter whose response is αZ^{-n} , that is, delayed by n taps and multiplied by α , where α can be a complex number. An output 909 of the filter 905 is subtracted from the next input sample 902 by a subtractor 903 to generate a slicer input 906. The output 909 is also summed with a slicer output 907 by a summer 904 to generate a modified slicer output 908. In receivers where an error estimate is needed for adaptation, such an estimate can be calculated by subtracting the slicer output 907 from the slicer input 906 or by subtracting the modified slicer output 908 from the

estimate 902. The latter calculation method realizes improved robustness for error propagation.

According to another embodiment of the present invention, channel throughput and communications robustness are increased using re-transmission techniques and/or diversity techniques. These techniques are particularly useful when the receiver is incapable of detecting the transmitted data from a single transmission. There are different MCNS channels, e.g., different time slots or different carrier frequencies.

Figure 10 depicts a general scheme that utilizes diversity and/or retransmission techniques over different MCNS channels according to this embodiment of the present invention. A 1:N rate encoder 1001 reproduces the current symbol or the current FEC block N times. Each reproduced symbol or block is transmitted using N MCNS signals 1002 to be communicated to the CMTS 103 of Figure 1 over N different channels 1003. It will be appreciated that the N channels represent physical (e.g., different carriers) and/or logical channels and can overlap in frequency. Outputs 1004 of the N channels are provided to a receiver 1005, which performs weighted soft-combining of the received signals 1004. The soft-combining comprises Mean Squared Error (MSE) estimation as well as identification of burst noise within the packet, followed by weighted or selective combining, as appropriate. The receiver can also incorporate joint equalization of the received signals.

The system in Figure 10 can also be interpreted as a retransmission technique in which the first MCNS signal transmitted over the first channel is the original message and all subsequent messages are requested by the CMTS 103 of Figure 1 one, or several, at a time to be retransmitted. According to a specific embodiment, a soft-combining method is applied to all the received messages.

For example, a retransmission request, possibly at a different carrier, can be sent from the CMTS 103 to the CM 101 of Figure 1 via the downstream channel 105 only if a Reed-Solomon block is received incorrectly. If a Reed-Solomon block is received incorrectly, then instead of requesting retransmission, the CMTS 103 tells the CM 101 what it received, so that the CM 101 can send to the CMTS 103 a short correction

message rather than sending the whole packet again. For example, the CMTS 103 may send back to the CM 101 an indication of the quality level of the detected symbols or the detected symbols themselves. Since the downstream channel 105 is much wider and more reliable than the upstream channel 106, this approach may be preferable.

5 Figure 11 depicts a particular retransmission scheme in which a different mapping for 16QAM is used for the retransmission. Two symbol mapping schemes are illustrated in Figures 12A-12B, in which A1, A2, A3, A4, B1, B2, B3, B4, C1, C2, C3, C4, D1, D2, D3, and D4 represent the sixteen combinations of four bits.

10 Figure 13 depicts a signal diversity system. In this system, two information bits $[b1(n) \ b2(n)]$, denoted by reference numeral 1301, per symbol are transmitted. The symbols are 16QAM and are mapped using a signal mapping block 1302 as a function of $[b1(n) \ b2(n) \ b1(n-D) \ b2(n-D)]$, where D is a delay introduced by a delay block 1303. Figure 14 depicts an example mapping scheme.

15 Using this approach, bursts of length D symbols can be recovered. In this approach, the carrier frequency may change between two transmissions of the same data. This change in carrier frequency can be used to protect from narrow band interference.

Conclusion

20 Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations of the invention will be apparent to those of ordinary skill in the art. Accordingly, this application is intended to cover any adaptations or variations
25 of the invention. It is manifestly intended that this invention be limited only by the following claims and equivalents thereof.

What is claimed is:

1. A transmission arrangement for transmitting a data signal using a cable television transmission medium, the transmission arrangement comprising:
an encoder configured to encode an input data stream as an encoder output signal;
a transmission filter arrangement, responsive to the encoder output signal and configured to reduce adjacent channel interference in the encoder output signal and to generate a filter output signal; and
a modulator, configured to modulate the filter output signal, generating a modulated radio frequency signal for transmission using the cable television transmission medium.
2. A transmission arrangement, according to claim 1, wherein the encoder is configured to encode the input data stream using a forward error correction code.
3. A transmission arrangement, according to claim 2, wherein the forward error correction code is a Reed-Solomon encoding scheme.
4. A transmission arrangement, according to claim 1, wherein the encoder comprises an interleaver configured to counteract at least one of impulse noise and burst noise.
5. A transmission arrangement, according to claim 1, wherein the transmission filter arrangement comprises a spectral shaping filter, a square-root raised cosine filter, a fixed shaping filter, and a trained pre-equalizer arranged in a cascaded configuration.

6. A transmission arrangement, according to claim 5, wherein the spectral shaping filter is configured to eliminate the effect of narrow band interference at a selected frequency.

7. A communication system for communicating a data signal using a cable television transmission medium, the communication arrangement comprising:

an encoder configured to encode an input data stream as an encoder output signal;

a transmission filter arrangement, responsive to the encoder output signal and configured to reduce adjacent channel interference in the encoder output signal and to generate a filter output signal;

a modulator, configured to modulate the filter output signal, generating a modulated radio frequency signal for transmission using the cable television transmission medium; and

a receiver arrangement coupled to receive the modulated radio frequency signal and configured to generate a stream of detected data based on the received modulated radio frequency signal.

8. A communication system, according to claim 7, wherein the receiver arrangement comprises:

an analog front end arrangement, configured to sample a desired signal from the received modulated radio frequency signal at less than the Nyquist rate and to cause thereby a shift in a center frequency of the desired signal from an initial frequency to a lower frequency;

a modified matched filter configured to perform a convolution of a square-root raised cosine filter and a pre-calculated filter and to generate a modified matched filter output signal;

an adaptive equalizer, responsive to the modified matched filter output signal and configured to generate an equalizer output signal; and

a decoder, responsive to the equalizer output signal and configured to decode the equalizer output signal and to generate the stream of detected data.

9. A communication system, according to claim 8, wherein the analog front end arrangement comprises:

a plurality of band pass filters coupled to receive the modulated signal, each of the band pass filters centered around a different frequency;

a multiplexer coupled to receive output signals from the band pass filters and to couple a selected one of the band pass filter output signals to an output of the multiplexer;

an analog to digital converter, responsive to the output of the multiplexer and to an output of a clock signal generator and configured to provide a digital signal, generated as a function of the output of the multiplexer and the output of the clock signal generator, to a digital receiver.

10. A communication arrangement, according to claim 9, wherein the analog front end arrangement further comprises sample rate logic configured to provide, as a function of the center frequency, a select signal to the multiplexer, a rate parameter to the clock signal generator, and a spectrum inversion indication to the digital receiver.

11. A communication system, according to claim 8, wherein the adaptive equalizer comprises an adaptive decision feedback equalizer.

12. A communication system, according to claim 8, wherein the pre-calculated filter comprises

a pre-equalizer, configured to reduce interference attributable to at least one of ISI and ingress noise associated with a communication channel, and

a $1+\alpha z^{-N}$ filter, coupled to the output of the pre-equalizer and configured to generate a filter output signal;

and wherein the receiver arrangement comprises
a Viterbi decoder, configured to generate a Viterbi decoder output signal as a function of the filter output signal; and
a forward error correction decoder, configured to generate a corrected decoder output signal in response to the Viterbi decoder output signal.

13. A communication system, according to claim 7, further comprising a modified slicer arrangement configured to produce an estimate of an original transmitted symbol.

14. A communication system, according to claim 13, wherein the modified slicer arrangement comprises:

- a slicer configured to estimate an output of the encoder;
- a filter having a response of αZ^{-N} ;
- a summing arrangement configured to add an output of the slicer to an output of the filter having a response of αZ^{-N} ;
- a subtracting arrangement configured to subtract the output of the filter having a response of αZ^{-N} from an input of the modified slicer;
- an error estimation arrangement, coupled to both an input and the output of the slicer and configured to estimate a receiver error; and
- a modified error estimation arrangement, coupled to both an input and the output of the modified slicer and configured to estimate the receiver error.

15. A communication system for communicating a data signal using a cable television transmission medium, the communication arrangement comprising:

- an encoder configured to encode an input data stream as an encoder output signal;
- a transmission filter arrangement, responsive to the encoder output signal and configured to reduce adjacent channel interference in the encoder output signal and to generate a filter output signal;

a modulator, configured to modulate the filter output signal, generating a modulated radio frequency signal for transmission using the cable television transmission medium;

an analog front end arrangement, configured to sample a desired signal from the modulated radio frequency signal at less than the Nyquist rate and thereby to cause a shift in a center frequency of the desired signal from an initial frequency to a lower frequency;

a modified matched filter configured to perform a convolution of a square-root raised cosine filter and a pre-calculated filter and to generate an modified matched filter output signal;

an adaptive equalizer, responsive to the modified matched filter output signal and configured to generate an equalizer output signal; and

a decoder, responsive to the equalizer output signal and configured to decode the equalizer output signal and to generate a stream of detected data.

16. An analog front end arrangement for use in a communication system for communicating a data signal using a cable television transmission medium, comprising:

a plurality of band pass filters coupled to receive a modulated radio frequency signal, each of the band pass filters centered around a different frequency, wherein a sampling rate is less than the Nyquist rate so as to cause aliasing deliberately;

a multiplexer coupled to receive output signals from the band pass filters and to couple a selected one of the band pass filter output signals to an output of the multiplexer;

an analog to digital converter, responsive to the output of the multiplexer and to an output of a clock signal generator and configured to provide a digital signal, generated as a function of the output of the multiplexer and the output of the clock signal generator, to a digital receiver; and

sample rate logic configured to provide, as a function of the center frequency, a select signal to the multiplexer, a rate parameter to the clock signal generator, and a spectrum inversion indication to the digital receiver.

17. A transmission method for transmitting a data signal using a cable television transmission medium, the transmission method comprising:
- encoding an input data stream as an encoder output signal;
 - filtering the encoder output signal to reduce adjacent channel interference in the encoder output signal, thereby generating a filter output signal; and
 - modulating the filter output signal to generate a modulated radio frequency signal for transmission using the cable television transmission medium.
18. A transmission method, according to claim 17, further comprising encoding the input data stream using a forward error correction code.
19. A transmission method, according to claim 18, wherein the forward error correction code is a Reed-Solomon encoding scheme.
20. A communication method for communicating a data signal using a cable television transmission medium, the communication method comprising:
- encoding an input data stream as an encoder output signal;
 - filtering the encoder output signal to reduce adjacent channel interference in the encoder output signal, thereby generating a filter output signal;
 - modulating the filter output signal to generate a modulated radio frequency signal for transmission using the cable television transmission medium;
 - receiving the modulated radio frequency signal; and
 - generating a stream of detected data based on the received modulated radio frequency signal.

21. A communication method, according to claim 20, further comprising:
sampling a desired signal from the received modulated radio frequency signal at less than the Nyquist rate and causing thereby a shift in a center frequency of the desired signal from an initial frequency to a lower frequency;
performing a convolution of a square-root raised cosine filter and a pre-calculated filter and to generate an modified matched filter output signal;
generating an equalizer output signal as a function of the modified matched filter output signal; and
decoding the equalizer output signal to generate the stream of detected data.
22. A communication method, according to claim 21, further comprising:
providing a select signal to the multiplexer as a function of the center frequency;
providing a rate parameter as a function of the center frequency; and
providing a spectrum inversion indication as a function of the center frequency.
23. A communication arrangement for communicating a data signal using a cable television transmission medium, the communication arrangement comprising:
a 1:N rate encoder, coupled to an input data stream and configured to reproduce a symbol or FEC block represented by a segment of the input data stream N times;
a transmission arrangement configured to use a plurality of outputs to transmit each reproduced symbol or FEC block using a distinct transmission channel; and
a receiver, coupled to the outputs of the transmission arrangement and configured to perform soft-combining of signals received from the outputs of the transmission arrangement and to output an estimate of the symbol or FEC block.
24. A communication arrangement, according to claim 23, wherein the soft-combining comprises at least one of mean squared error estimation, identification of burst noise within a data packet, weighted combining, and selective combining.

25. A communication arrangement, according to claim 23, wherein one of the transmission channels is used to transmit an original message and the remaining transmission channels are used to perform retransmission.
26. A communication arrangement, according to claim 23, wherein a plurality of information bits are used to represent a symbol to be transmitted, and wherein the transmission channels are used to transmit the information bits using a delay-encoded mapping scheme.
27. A communication method for communicating a data signal using a cable television transmission medium, the communication method comprising:
reproducing a symbol or FEC block represented by a segment of an input data stream a preselected number of times;
using a plurality of transmission channels to transmit each reproduced symbol or FEC block using a distinct transmission channel; and
performing soft-combining of signals received from the transmission channels.
28. A communication method, according to claim 27, wherein the soft-combining comprises at least one of mean squared error estimation, identification of burst noise within a data packet, weighted combining, and selective combining.
29. A communication method, according to claim 27, further comprising:
transmitting an original message using one of the transmission channels; and
performing retransmission using the remaining transmission channels.
30. A communication method, according to claim 27, further comprising:
using a plurality of information bits to represent a symbol to be transmitted; and
using the transmission channels to transmit the information bits using a delay-encoded mapping scheme.

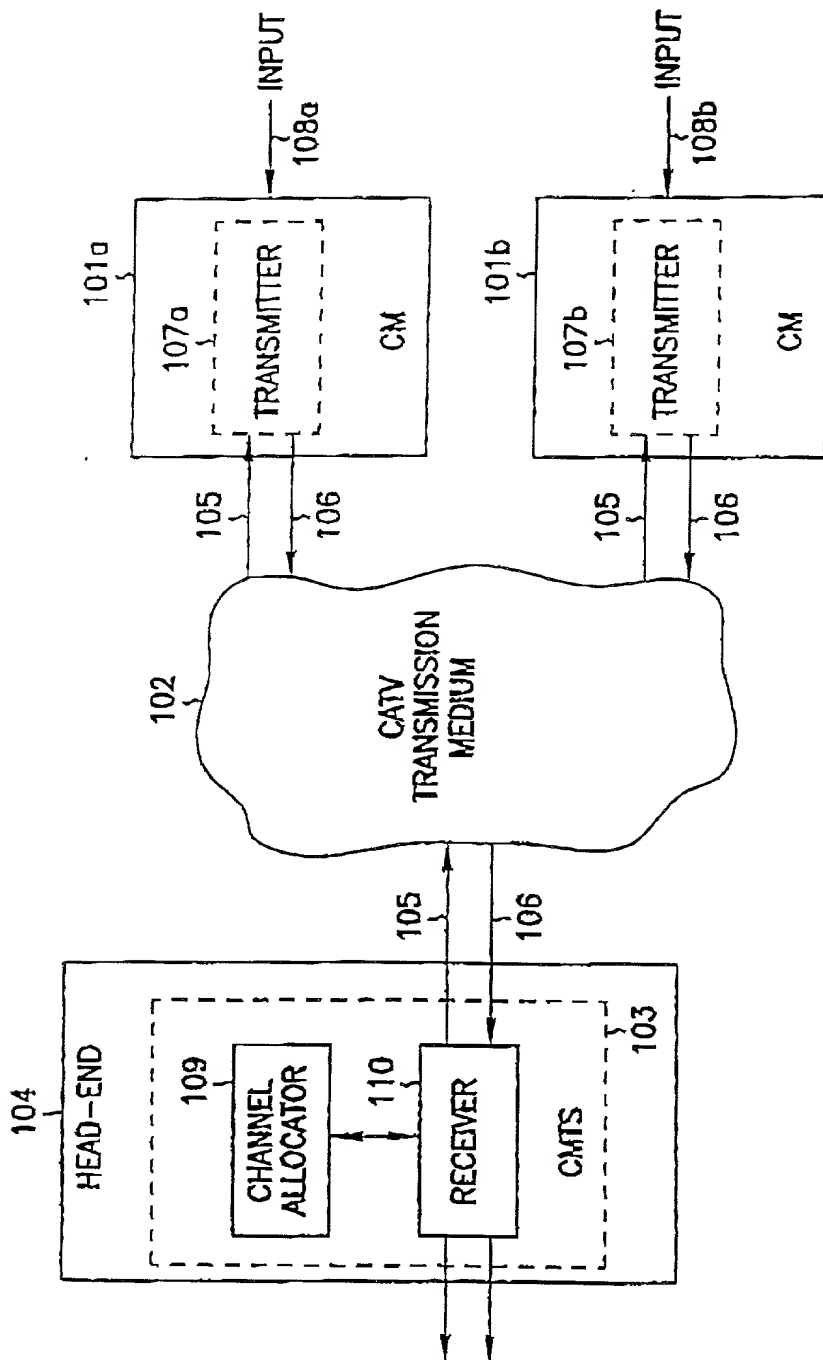


FIG. 1

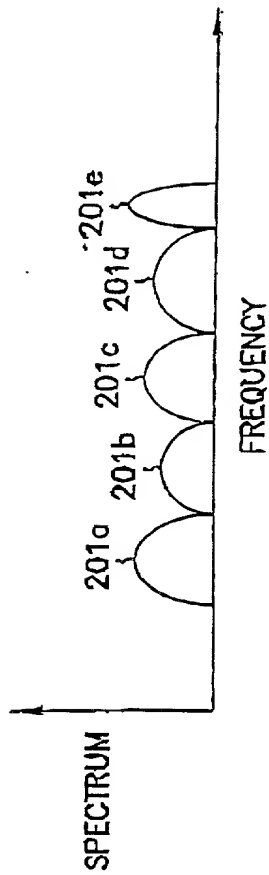


FIG. 2

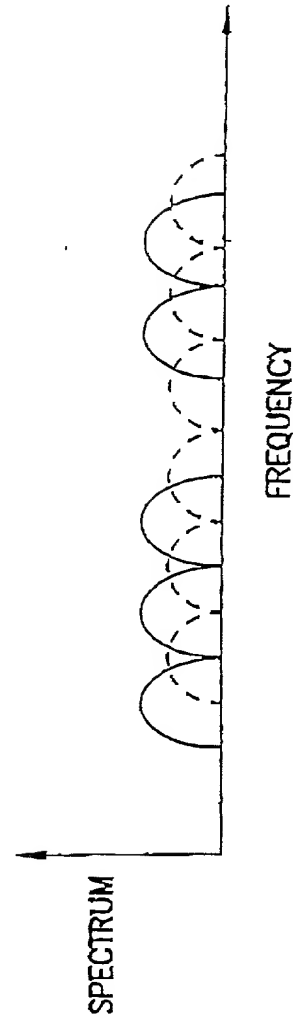


FIG. 3

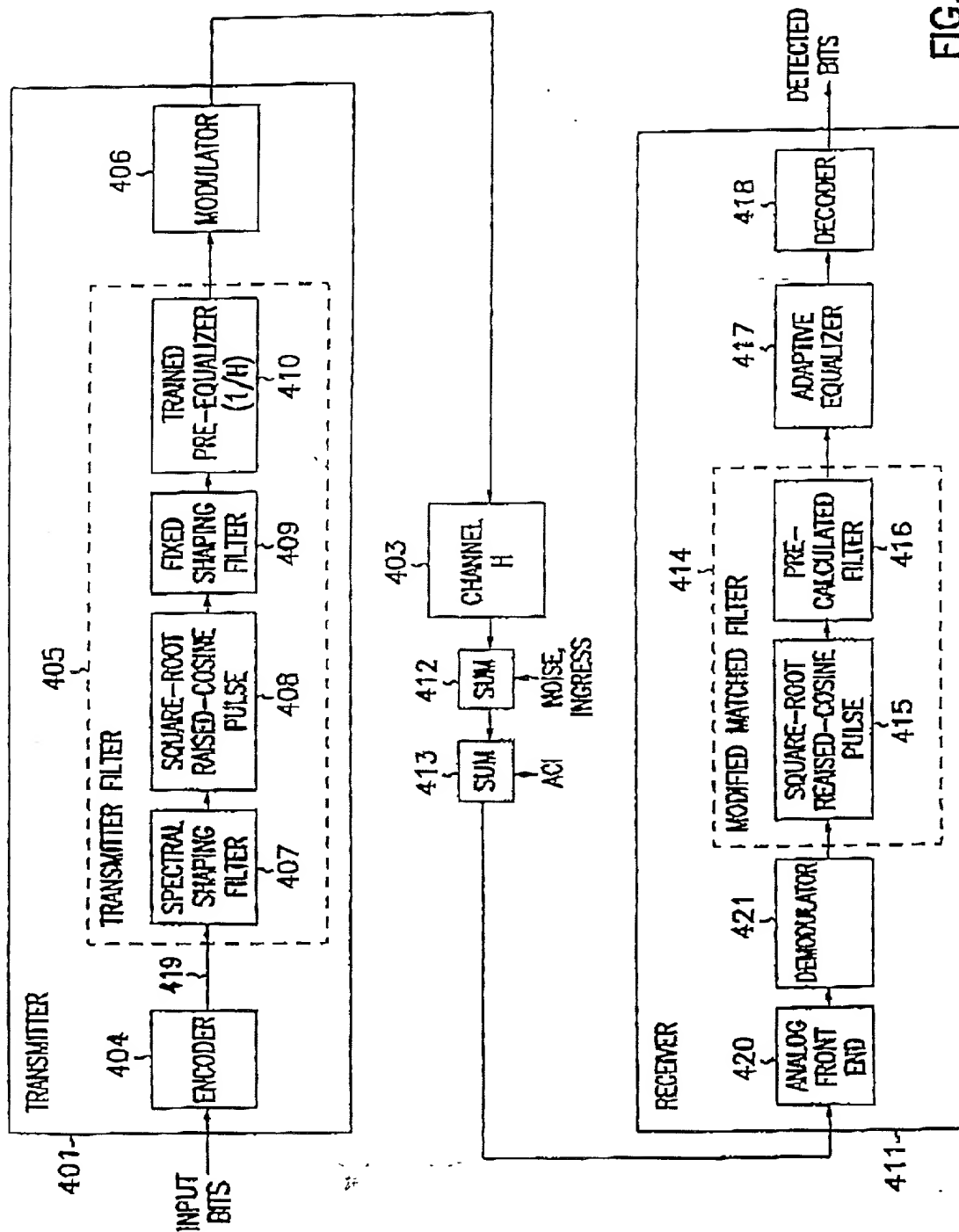
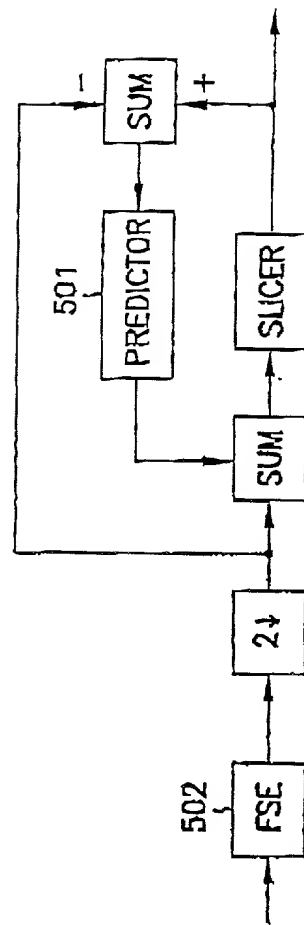


FIG. 4



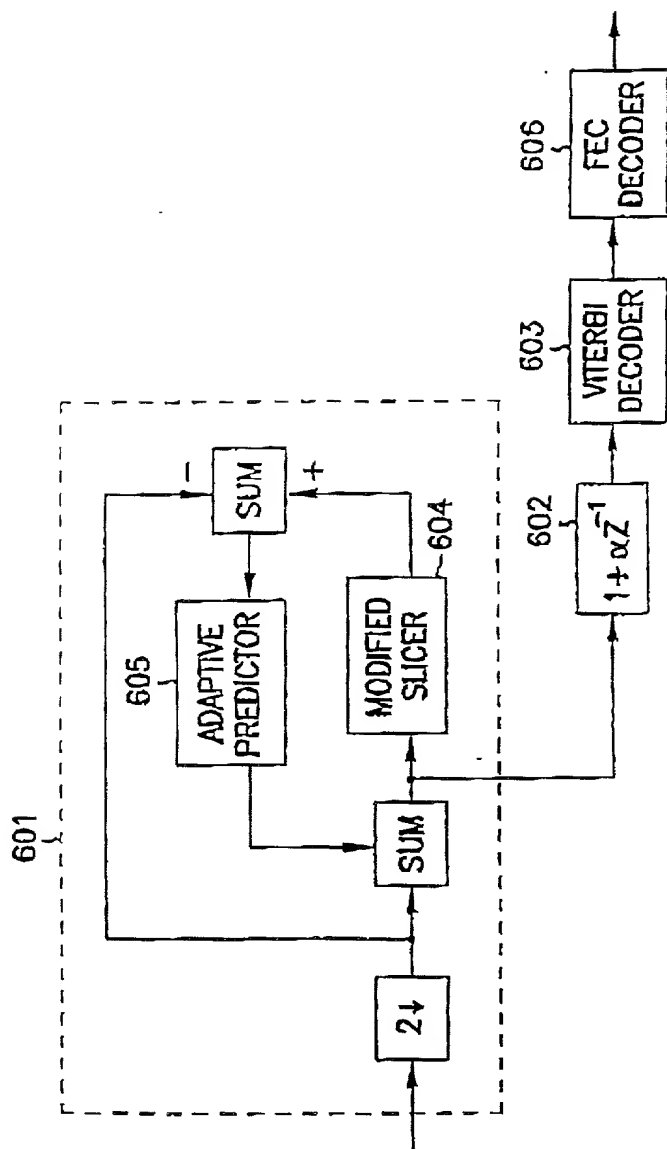


FIG. 6

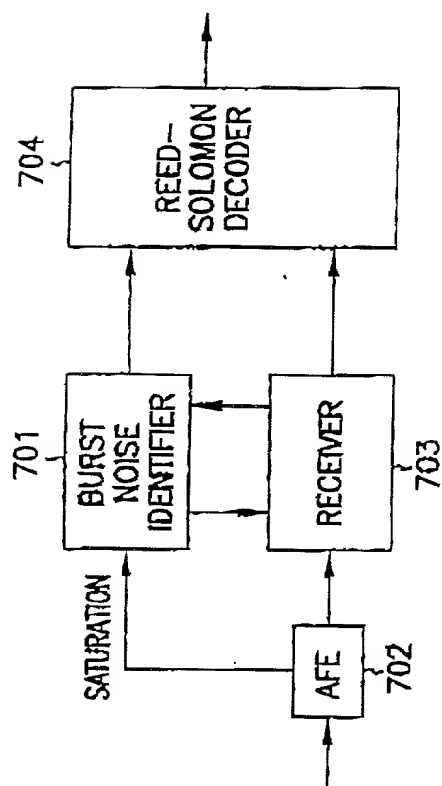
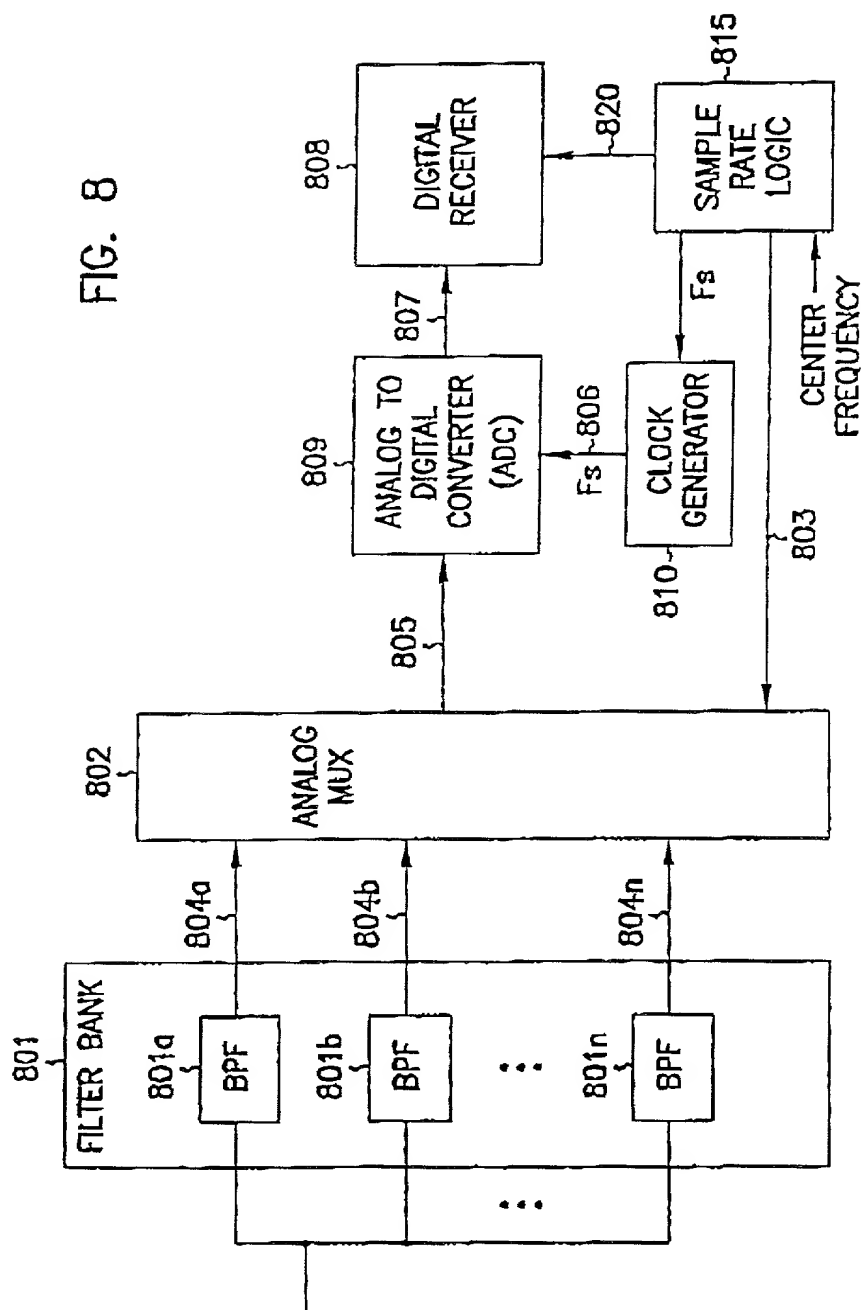


FIG. 7





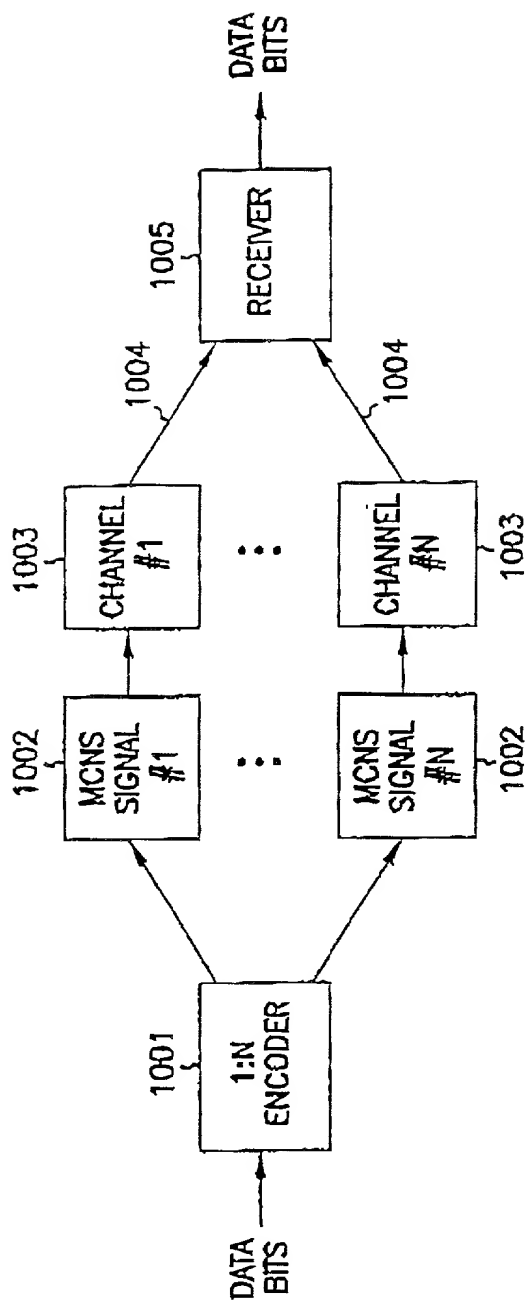


FIG. 10

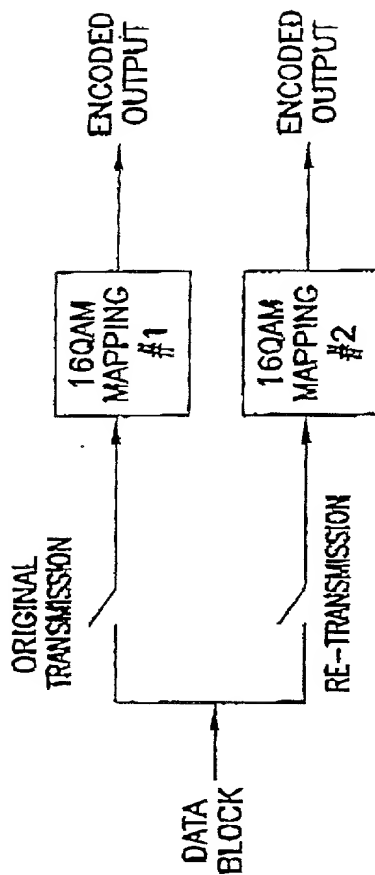


FIG. 11

11/13

FIRST SYMBOL				SECOND SYMBOL			
A1	A2	A3	A4	C3	C1	C4	C2
B1	B2	B3	B4	A3	A1	A4	A2
C1	C2	C3	C4	D3	D1	D4	D2
D1	D2	D3	D4	B3	B1	B4	B2

FIG. 12A

FIRST SYMBOL				SECOND SYMBOL			
A1	A2	A3	A4	C2	C4	C1	C3
B1	B2	B3	B4	A3	A1	A4	A2
C1	C2	C3	C4	D2	D4	D1	D3
D1	D2	D3	D4	B3	B1	B4	B2

FIG. 12B

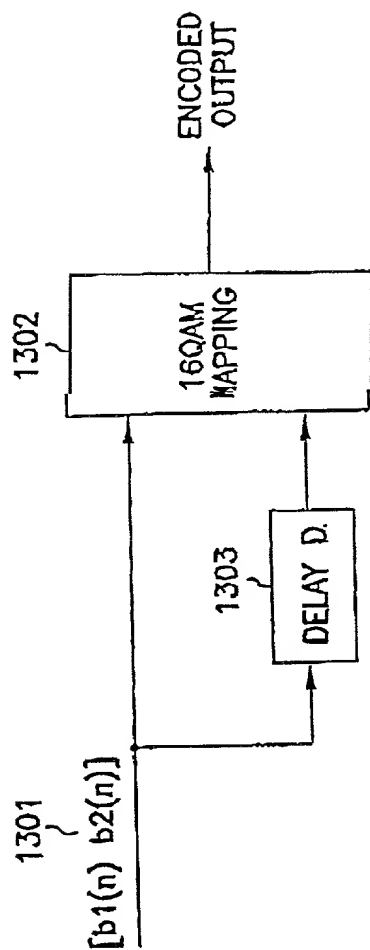


FIG. 13

13/13

0000	0001	0100	0101
0011	0010	0111	0110
1100	1101	1000	1001
1111	1110	1011	1010

FIG. 14

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TI-30245-1

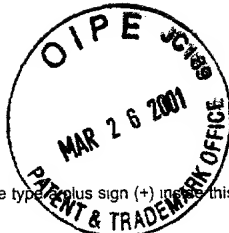
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I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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First Named Inventor	Mordechai Segal
Group Art Unit	TBD
Examiner Name	TBD
Attorney Docket Number	T1-30245

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Texas Instruments Incorporated
Wade James Brady III, Deputy General Patent Counsel & Vice President

Signature

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3/22/01

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Filing Date	11/01/00
First Named Inventor	Mordechai Segal
Group Art Unit	TBD
Examiner Name	TBD
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Signature	<i>Wade James Brady III</i>
Date	3/22/01

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